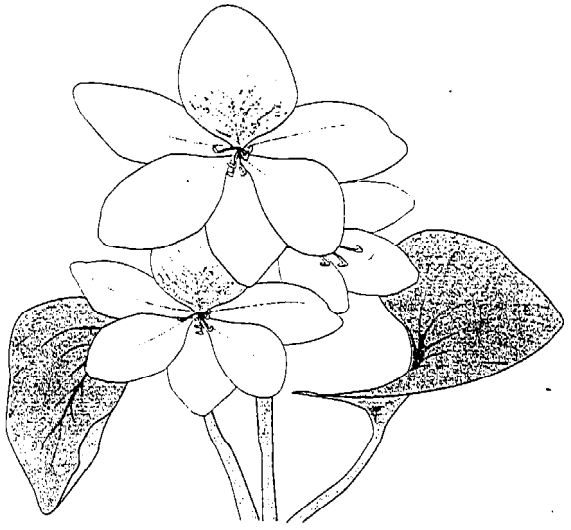
◆ INVASIVE AQUATIC PLANTS



INTRODUCTION

Weeds, or invasive plant species, are types of vegetation capable of exploiting opportunities afforded by natural or human-related disturbances in the landscape, as well as those provided by relatively undisturbed habitats. Although not all weeds are non-native, most have been introduced from other parts of the world.

Invasive aquatic plants have become sufficiently established in some locations to threaten the health of the Bay-Delta ecosystem. The aquatic plants that pose the greatest threats to aquatic ecosystems are those that directly or indirectly affect rare native species, decrease foodweb productivity, and reduce populations of desired fish and wildlife species.

Factors that relate to the degree of influence invasive aquatic plants have on the Bay-Delta include additional introductions from ship ballast and other sources and local water quality and hydrologic conditions that favor their establishment.

STRESSOR DESCRIPTION

Lacking the controls found in their native habitat (e.g., specific insects for which they are a food source or toxins produced by competing plants), these plants can flourish in a new landscape, gaining a competitive advantage over the native species. Many weeds have evolved characteristics that make them extraordinarily competitive in both natural and introduced environments, such as high seed production; mechanisms for effective seed dispersal; rapid growth rate; and adaptability to extremes in temperature, nutrients, and water availability.

A species is considered a weed problem because of its ability to adversely affect natural communities or human land use requirements. Introduced or native aquatic plant species are considered harmful when they reduce the biological diversity of existing natural communities by displacing native species or altering ecosystem processes such as nutrient cycling, hydrologic conditions, or water chemistry. They create problems for human society when they impair agricultural or aquacultural productivity, constrict waterways, diminish recreation and aesthetic values, or destroy structures.

Most aquatic weeds were introduced to California waterways unintentionally. They were brought in as pond ornamentals (e.g., water hyacinth) and aquarium plants (e.g., hydrilla), or through dispersal by boats. Aquatic weeds have been here for at least 100 years; water hyacinth was discovered in a Yolo County slough in 1904. Hydrilla, which was probably introduced through its use as an aquarium plant, has been in California for at least 20 years. Egeria, still a popular aquarium plant, has been in the ecosystem for over 30 years.

Most aquatic weeds pose a threat to the aquatic foodweb and rare aquatic or riparian species because they form dense mats that block sunlight or deplete oxygen supplies. The sheer mass of floating tissue can also impede navigation and damage water control structures. Establishment of invasive aquatic plants can harm or kill rare and valued fish, native plants, and other aquatic organisms; reduce biodiversity; impede navigation; damage water control structures; and increase mosquito habitat.

Many stream and river channels in the Delta and the Sacramento and San Joaquin Rivers and their tributaries have been channelized, confined by levees,

impounded, and otherwise altered from their shapes of 150 years ago. With the conversion of adjacent riparian communities to other land uses, the ecosystem processes and functions have changed substantially. These changes stress native aquatic flora and fauna, leading to changes in species composition and population densities, and perhaps making the aquatic foodweb more vulnerable to further stressors.

Most weeds that infest the Delta and the Sacramento and San Joaquin Rivers and their tributaries are problems in specific locations, not throughout these waterways; however, locations of aquatic weeds have not been comprehensively mapped. The California Department of Food and Agriculture's Integrated Pest Control Branch records locations where aquatic weeds, such as hydrilla, pose a threat to agriculture. Locations of weeds that threaten natural areas are not recorded. Comprehensive mapping throughout the ERPP study area is needed for all weeds that threaten aquatic habitat as a first step to monitoring and controlling infestations.

Some non-native aquatic weeds that pose the most serious threats and need further research, monitoring and mapping, or control are egeria, hydrilla, water hyacinth, water pennywort, eurasian watermilfoil and parrot feather. Each of these is described below. These weeds flourish in a wide geographic area, sometimes in high densities, and are extremely dangerous because of their ability to displace native plant species, harm fish and wildlife, reduce foodweb productivity, or interfere with water conveyance and flood control systems.

EGERIA (*Egeria densa*; syn: *Elodea densa*): A native of South America, egeria is a popular aquarium plant, which most likely accounts for its introduction into California waterways. It is a submerged, rooted perennial that occupies the same littoral zone niche in slow-moving water as native pondweeds, thereby potentially excluding the pondweeds and reducing the habitat value for waterfowl that eat pondweeds. Egeria creates a structure having much more branching than pondweeds. It forms dense mats that block sunlight and reduce the amount of open water, leading to increased accretion of organic material and increased sedimentation. The dense mat structures may impede diving waterfowl from foraging, and the increased sedimentation may alter the population of benthic species and their predators.

Egeria has been in the Delta for perhaps 30 years or more but probably was not a major problem until the past 12 years, coinciding with the water hyacinth control program. Removing water hyacinth from waterways and a 6-year drought may have contributed to the expansion of coverage by egeria (Anderson pers. comm.).

Egeria currently infests approximately 3,000 acres, primarily in the Delta. The success of this infestation in the Delta is indicative of the greater success that hydrilla would have if it were not prevented from establishing there. Hydrilla, unlike egeria, has long-lived rhizomes, making it much more difficult to control. Egeria is listed as a "B"-rated noxious weed by the California Department of Food and Agriculture's Noxious Weed Program. This designation does not mandate its control and, because the species is so widespread, little attention has been paid to controlling it. Now that growing populations are increasingly obstructing water conveyance structures and natural wetlands, the California Department of Boating and Waterways is given $500,000 per year to control egeria along with water hyacinth (Anderson pers. comm.). Returning native pondweeds to an egeria-infested site would probably require active restoration once the egeria is removed.

HYDRILLA (*Hydrilla verticillata*): A submerged perennial, hydrilla was introduced to North American waterways sometime after 1956 through its use as an aquarium plant. It has since spread throughout the country, infesting waterways, irrigation canals, lakes, and ponds. It can completely fill and clog waterways, restricting flow, increasing sedimentation, and hindering navigation and public water use. Like egeria, hydrilla forms dense mats that block light, deplete oxygen, and increase sedimentation and organic deposition. In slow-moving water and oxbows, hydrilla can deplete oxygen and resources to the point of causing fish kills. Unlike egeria, however, hydrilla forms rhizomes that live 5-7 years and from which new plants can grow. Because of the persistence of rhizome viability, hydrilla will be much more difficult to remove from the Delta, if it establishes there, than egeria.

Hydrilla is an "A"-rated weed in the California Department of Food and Agriculture's Noxious Weed Program. This designation means that the plant poses a serious problem to agriculture but may be contained through control efforts. Since 1976,

when it was first noticed, the California Department of Food and Agriculture has spent $20 million to eradicate hydrilla (California Exotic Pest Plant Council Biocontrol Committee 1995). Hydrilla has been found in 17 counties in California and has been eradicated from nine counties. Thus far, it has been prevented from establishing in the Delta. An example of its invasiveness can be seen in Clear Lake in northern California, where it now covers about 650 acres of the lake's 43,000-acre surface area.

WATER HYACINTH (*Eichhornia crassipes*): A floating perennial, water hyacinth is native to South America. It infests streams, ponds, backwater areas, ditches, sloughs, and waterways. It grows rapidly in the summer, floating and spreading by means of buoyant stolons and seed. Water hyacinth was introduced to the United States in 1884 when it was given to visitors as souvenirs at the Cotton States Exposition. Water hyacinth was first reported in California in a Yolo County slough in 1904. Today, it is a serious pest in the Delta, the Sacramento and San Joaquin Rivers, and many sloughs and tributaries, where it clogs waterways, obstructs commercial and recreational navigation, and impedes water conveyance.

Water hyacinth is also a serious problem for the pumping and fish-screening facilities in the south Delta. Forming a dense cover over the water surface, it blocks sunlight, reduces water flow, depletes oxygen, and inhibits gaseous interchange with the air, all of which harm other aquatic organisms. Water hyacinth increases mosquito habitat by providing larval breeding sites where mosquito predators cannot reach. In backwater areas, dense concentrations of water hyacinth can increase fish mortality. It also increases sedimentation and the accretion of organic matter. Water hyacinth reportedly competes with Mason's lilaeopsis (*Lilaeopsis masonii*), an endangered freshwater emergent plant native to California (Van Ways pers. comm.).

In 1982, the California Department of Boating and Waterways formed a task force to begin controlling water hyacinth, testing different mechanical and herbicidal control methods. In 1996, the department spent $900,000 to treat 1,750 acres of water hyacinth, mostly in the central and southern Delta (Van Ways pers. comm.). Some control efforts involve aerial spraying of herbicides, but in many areas herbicides must be applied from boats. Since water hyacinth control began, egeria populations have expanded. Egeria clogs boat propellers quickly and has made continued control of water hyacinth much more difficult. As a result, the department has now been given approval and funding to control both egeria and water hyacinth.

WATER PENNYWORT (*Hydrocotyle umbellata*): A perennial native plant, water pennywort grows along streambanks and in ponds, canals, and marshy areas. It forms stems that float and creep along wet soil. Although it takes root, plants also break off and form dense, floating rafts that drift. These rafts can cause some of the same problems seen with water hyacinth. Since water hyacinth has been controlled, the pennywort population has increased and become a weed problem in some areas. (Anderson pers. comm.).

EURASIAN WATERMILFOIL (*Myriophyllum spicatum*) and **PARROTFEATHER** (*Myriophyllum aquaticum*): Both Eurasian watermilfoil and parrotfeather are submerged perennials. Eurasian watermilfoil, as its name suggests, is native to Eurasia; parrotfeather is native to South America. Parrotfeather is sold in nurseries for aquariums and backyard ponds. Eurasian milfoil is much more abundant statewide than parrotfeather; however, no comprehensive surveys have measured the extent of these two weeds. Because Eurasian milfoil has not created a specific problem for agriculture, it has not been targeted for control. An example of a Eurasian milfoil infestation is in Lake Tahoe, where it covers about 200 surface acres, mostly in the marina area. Parrotfeather is found in seasonally wet streams, small lakes, and flood control channels. An example of its infestation is found in Parks Lake on Beale Air Force Base.

Like hydrilla and egeria, both of these plants occupy areas where native pondweeds would grow. Eurasian milfoil grows mostly submerged, whereas parrotfeather extends above the water. The growth form of parrotfeather results in substantial increases in mosquito habitat. Although both plants may present problems, they can be beneficial to aquatic habitat as well. Parrotfeather is thought to provide cover for aquatic organisms, and Eurasian milfoil stems and fruits are eaten by waterfowl (Westerdahl and Getsinger 1988).

ISSUES AND OPPORTUNITIES

Develop means to control invasive aquatic plants in the Delta. Invasive plants, such as water hyacinth and Egeria densa (Brazilian water weed), are clogging many sloughs and waterways of the Delta, not only impeding boat traffic, but also creating environments that are unfavorable for native fishes. The California Department of Boating and Waterways has an Egeria control program, but has not yet received CEQA approval for use of chemical controls. There is an immediate need to develop ways by which to control these plants that are not, in themselves, environmentally harmful. An opportunity exists for the ERP to join forces implementing ambitious eradication and control measures with agencies, organizations, and water districts concerned with the deleterious effects of these water weeds on navigation in the Delta, clogging of water intakes and fish screens, and diminished recreational uses (Strategic Plan 2000).

VISION

The vision for invasive aquatic plants is to reduce their adverse effects on native species and ecological processes, water quality and conveyance systems, and major rivers and their tributaries.

Active management of Delta streams and rivers is necessary to reduce the surface area of channels and sloughs in the Delta that are covered by water hyacinth and other invasive aquatic plant species. To effectively control aquatic weeds, existing programs will need to be expanded and funded or new programs created. Currently, locations for hydrilla and noxious weeds that pose a threat to agriculture are reported as part of the California Department of Food and Agriculture's Integrated Pest Control Program; however, weeds posing a threat to natural habitats are not mapped. An improved mapping and monitoring program that efficiently maps and monitors all targeted weeds will aid in their control, especially for rapidly spreading species. Such a program will also help to assess changes in the population levels and the effectiveness of control programs. Expanding California's noxious weed program to include weeds that pose a threat to native species or habitats would also aid in building an effective long-term aquatic weed control program.

To facilitate effective control programs for these species, all groups involved must coordinate with one another to control and restore habitat in Delta waterways. A coordinated approach to eliminate all damaging weeds, rather than only selected weed species, can reduce instances where one weed infestation replaces another, as exemplified by the increases in egeria and pennywort populations following efforts to control water hyacinth. In addition, regulatory agencies and those obligated to implement control programs must coordinate their efforts to plan and implement those programs that are appropriate to meet the specific needs of each site. Because the ecological, recreational, water quality, water conveyance, and commercial needs vary at each site, a general control strategy or regulatory policy is not possible. The specific needs of a site must be assessed and the costs and risks of different control strategies must be compared to determine the most appropriate strategy for each site. As a result, some sites will require more restrictive strategies than others.

INTEGRATION WITH OTHER RESTORATION PROGRAMS

The California Department of Food and Agriculture's Integrated Pest Control Branch tracks and controls federally listed noxious weeds throughout the State. These are weeds that have an impact on agriculture, although most of the current infestations are restricted to natural and uncultivated areas. Listed weeds are given a letter designation: "A" weeds are tracked and targeted for control or eradication wherever they are found; "B" weeds are considered too widespread to require mandated control of them, and the decision to control them is left to the county agricultural commissioners; "C" weeds are so widespread that the agency does not endorse State- or county-funded eradication or control efforts except in nurseries and seed lots.

Of the weeds described in this vision statement, only hydrilla is listed as a noxious weed. With funding, the California Department of Food and Agriculture's Integrated Pest Control Branch could be expanded to include weeds that adversely affect natural areas and their existing infrastructure and the expertise of that branch could be used to track, map, and control weeds that pose problems in natural areas.

Two recently announced programs or policy changes

may have a beneficial effect on the vision for controlling invasive non-native aquatic and riparian weeds. The first is a new weed policy developed by the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS) that regulates not only weeds that threaten agricultural or managed areas, but those affecting natural areas as well. This program will use a risk assessment to identify weeds federally listed as noxious. Among other aspects of the new policy, APHIS will have a regulatory role, detecting, assessing, and containing incipient infestations. The policy states that APHIS will act in a federal coordination role to facilitate communication and cooperation among relevant public agencies and others (Westbrooks 1995).

The second new approach was formed through a Memorandum of Understanding (MOU) signed in 1994 by 17 land-holding federal agencies. The Federal Interagency Committee for Management of Noxious and Exotic Weeds was formed, under the MOU, to enable the signing agencies to cooperatively manage noxious and non-native weeds on federal lands and to provide technical assistance on private land to achieve sustainable, healthy ecosystems that meet the needs of the society (Jackson 1995).

Many other organizations have weed issues in the Delta, all with different roles, interests, and expertise. Implementing the ERPP vision requires a coordinated effort among these groups to develop and implement weed management programs and strategies that will help meet ERPP's goals for the various resources and ecological management zones.

- The U.S. Department of Agriculture - Agricultural Research Service Aquatic Weed Control Research Laboratory in the Department of Vegetable Crops at the University of California at Davis conducts ongoing research on aquatic weed control.
- The California Weed Science Society is a 50-year-old organization serving the weed science community.
- The California Exotic Pest Plant Council is a nonprofit organization that focuses on issues regarding non-native pests and their control and educates the public on these issues.
- The U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, California Department of Fish and Game, State Water Resources Control Board, Central Valley Regional Water Quality Control Board, California Department of Food and Agriculture, and California Department of Health Services have regulatory or programmatic roles pertaining to aquatic weed control in the Delta and the Sacramento and San Joaquin Rivers and their tributaries.

In addition to these, several public and private groups deal directly or indirectly with aquatic weeds in the Delta. Among them are:

- California Native Plant Society,
- The Nature Conservancy,
- the State and national parks systems, county and local parks departments,
- Animal and Plant Health Inspection Service ,
- U.S. Army Corps of Engineers,
- U.S. National Resources Conservation Services,
- Center for Natural Lands Management,
- resource conservation districts, mosquito abatement districts, flood control districts,
- California Association of Nurserymen,
- local land trusts,
- and private landowners.

LINKAGE WITH OTHER ECOSYSTEM ELEMENTS

Invasive aquatic plants adversely influence other ecosystem elements including ecological processes, habitats, and species. For example, introduced species have out competed and displaced many native species. The proliferation of exotic plants has impaired the proper functioning of fish protective devices such as fish screens and fish louvers in the Delta.

OBJECTIVES, TARGETS, AND ACTIONS

Two Strategic Objectives address invasive aquatic plants.

The first Strategic Objective is to halt the introduction of invasive aquatic and terrestrial plants into the Bay-Delta estuary, its watershed, and other central California waters.

LONG-TERM OBJECTIVE: Halt the release and spread of aquarium organisms, exotic plants and aquatic pets in the Bay-Delta Watershed.

SHORT-TERM OBJECTIVE: Develop and institute strategies, working with the aquarium industry and interests representing the environment and other sectors that may be affected by such introductions, to halt the introduction and spread of non-native species and exotic plants from the aquarium and pet trades.

RATIONALE: Many kinds of aquatic organisms are sold in aquarium and pet stores. It is likely that some species of nuisance aquatic plants (e.g., Hydrilla) became established through aquarists dumping them in local waterways. Non-native turtles originating in pet stores are frequently present in ponds and have the potential to displace and spread diseases to native pond turtles. Although many organisms sold in aquarium stores are tropical and unlikely to survive in Central California (with some surprising exceptions), the industry is constantly searching for and bringing in new species from a variety of habitats. As indicated in the ballast water rationale, new species can have unexpected and sometimes large-scale negative impacts on aquatic ecosystems and can make restoration much more expensive and difficult. There clearly is a need to make sure that potentially harmful organisms are not available to aquarists and that new organisms are not brought in as "hitch-hikers" in shipments of aquarium fishes. There is also a need to better educate the public on the adverse impacts of invasive species and the need to not release aquatic pets into natural environments. A good model for this could be the program now in place in Hawaii, which (among other things) has a big public education component and requires all aquarium stores to have a special tank into which people can release unwanted aquatic organisms.

STAGE 1 EXPECTATIONS: Species in the aquarium and pet trades will have been identified and evaluated for their ability to establish populations in the Bay-Delta system. With the cooperation of the aquarium/pet industry and affected interests, a plan will have been developed and instituted to greatly reduce, and eventually eliminate, the introduction of unwanted aquatic organisms from these sources into natural waters.

The second Strategic Objective is to limit the spread or, when possible and appropriate, eradicate populations of nonnative invasive species through focused management efforts.

LONG-TERM OBJECTIVE: Eliminate, or control to a level of little significance, all undesirable non-native species, where feasible.

SHORT-TERM OBJECTIVE: Eradicate or contain those species for which this can readily be done, gaining thereby the largest benefit for the least economic and environmental cost; and to monitor for the arrival of new invasive species and, where feasible, respond quickly to eradicate them.

RATIONALE: Non-native species are now part of most aquatic, riparian, and terrestrial ecosystems in California. In most instances, control is either not possible or not desirable. However, in some instances, control of invasive species is needed to protect the remaining native elements or to support human uses. Four factors should be considered in focusing control efforts. First, an introduced species is often not recognized as a problem by society until it has become widespread and abundant. At that point, control efforts are likely to be difficult, expensive, and relatively ineffective, while producing substantial environmental side effects or risks, including public health risks. Second, some organisms, by nature or circumstance, are more susceptible to control than others. Rooted plants are in general more controllable than mobile animals, and organisms restricted to smaller, isolated water bodies are in general more controllable than organisms free to roam throughout large, hydrologically connected systems. Third, although biological control is conceptually very

appealing, it is rarely successful and always carries some risk of unexpected side effects, such as an introduced control agent "controlling" desirable native species. And fourth, physical or chemical control methods used in maintenance control rather than eradication require an indefinite commitment to ongoing environmental disturbance, expense, and possibly public health risks. Overall, the most efficient, cost-effective, and environmentally beneficial control programs may be those that target the most susceptible species, and species that are not yet widespread and abundant. This suggests a need to (1) assess the array of introduced species and focus on those that are most amenable to containment and eradication, rather than focusing just on those that are currently making headlines, and (2) responding rapidly to eradicate new introductions rather than waiting until they spread and become difficult or impossible to eradicate.

An example of a "rare" introduced species needing eradication that is not being dealt with is English cordgrass in the Bay. It has been described by some scientists as the most aggressive and invasive salt marsh plant in the world. It has been in the Bay, its only known California location, for 20 years without spreading, so it has not generated concern. However, in other parts of the world it has also sometimes sat around for a few decades without doing much of anything, then suddenly taken off and taken over entire estuaries in a few years. In San Francisco Bay, it is known from one site only, where it was planted, and where it exists in a single patch. It could readily be eradicated.

An example of an abundant species needing immediate attention is the water weed Egeria densa. This plant has been spreading rapidly through the Delta, where it clogs sloughs and channels with its dense growth, creating problems for navigation. From a biological perspective, it is undesirable because E. densa beds appear to exclude native fishes and favor introduced species.

STAGE 1 EXPECTATIONS: An assessment will be completed of existing introductions to identify those with the greatest potential for containment or eradication, and consider this in prioritizing control efforts. A program will have been implemented to monitor for, and respond quickly to contain and eradicate new invasions, where this is possible. A mechanism whereby new invasions can be dealt with quickly and effectively will have been developed an implemented.

RESTORATION ACTIONS

A comprehensive strategy to reduce invasive aquatic plants and their adverse effects on the Bay-Delta ecosystem would include the following items.

- Assess aquatic weeds for their level of threat, their extent, and their potential to be controlled in the long run.
- Assess potential weed control sites to determine how effective control efforts will be in improving habitat quality, the longevity of results, and the sites' likelihood of providing the types of habitats and habitat characteristics proposed for restoration.
- Develop and implement management plans to achieve specific targets for each weed and site.
- Implement habitat restoration (e.g., planting native pondweeds and other desirable aquatic and emergent wetland plants) concurrent with or following implementation of control measures, where appropriate.
- Eradicate water hyacinth from major tributaries and marinas, locks, important wetland areas, and wildlife refuges in the Sacramento-San Joaquin Delta Ecological Zone.
- Elsewhere, reduce the biomass of infested acreage to a lower maintenance level than of the present summer cover. This goal would be approached beginning in the tributaries entering the Delta, and aiming for total eradication there; then water hyacinth will be contained at maintenance levels in upstream locations.
- Provide technical expertise, serve as a clearinghouse for regional information and project results, and assist with implementation of high-priority local projects in specific ecological units or zones to increase the effectiveness of existing public and private programs to reduce the threat of invasive species.

REFERENCES

California Exotic Pest Plant Council Biocontrol Committee. 1995. Biological control of invasive exotic pest plant species - a report on the

importance of maintaining and enhancing our nation's biological control capabilities. Cal EPPC News. California Exotic Pest Plant Council.

Jackson, N. 1995. Update: Federal Interagency Committee for Management of Noxious and Exotic Weeds (FICMNEW). Abstracts of the California Exotic Pest Plant Symposium '95. Cal EPPC News. California Exotic Pest Plant Council.

Strategic Plan for Ecosystem Restoration. 2000. CALFED Bay-Delta Program, Programmatic EIS/EIR Technical Appendix. July 2000.

Westbrooks, R. G. 1995. Federal regulatory efforts to minimize the introduction and impacts of exotic pest plants in the United States. Abstracts of the California Exotic Pest Plant Symposium '95. Cal EPPC News. California Exotic Pest Plant Council.

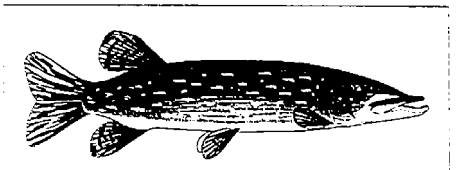
Westerdahl, H. E., and K. D. Getsinger (eds.). 1988. Aquatic plant identification and herbicide use guide. Volume II: Aquatic plants and susceptibility to herbicides. November. (Technical Report A-88-9.) U.S. Army Corps of Engineers. Washington, DC.

PERSONAL COMMUNICATIONS

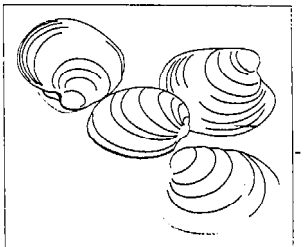
Anderson, Lars. Research leader. U.S. Department of Agriculture - Agricultural Research Service Aquatic Weed Control Research Laboratory, Department of Vegetable Crops, University of California, Davis, Davis, CA. February 2, 1997 - telephone conversation.

Van Ways, Valerie. Supervisor. Aquatic Weed Program, California Department of Boating and Waterways. October 3, 1996 - telephone conversation.

◆ INVASIVE AQUATIC ORGANISMS



Northern Pike



Asian Clams

INTRODUCTION

Most of the clams, worms and other bottom-dwelling invertebrates presently inhabiting the Bay-Delta are introduced from other estuaries. Non-native species also make up an increasing proportion of the zooplankton and fish communities of the Bay-Delta. It is estimated that a new non-native species is identified in the Bay-Delta every 15 weeks.

Many species were transported on the hulls of ships or in ship ballast water. Others arrived with the Atlantic or Japanese oysters purposely introduced into the estuary earlier in this century. Many fish, including striped bass, American shad, and largemouth bass, were introduced by federal and State resource agencies to provide sport fishing or forage fish to feed sport fish. Others, such as the northern pike, in a western Sierra reservoir, were purposely and illegally introduced.

Whether accidental or intentional, the introductions of these organisms have greatly increased the species diversity of the Bay-Delta aquatic community. However, this increase in diversity has occurred at the expense of native species, some of which have declined precipitously or even become extinct because of predation and competition from non-natives. Some introduced species are nuisances because they attach to boat hulls, bore into dock pilings, clog drainage pipes, tunnel into levees, or compete with or prey on valuable native species. Many non-native species, however, perform vital ecological functions such as serving as primary consumers of organic matter, or as a food source for Bay-Delta fish, shorebird, waterfowl, and other wildlife populations. Many non-native species have invaded the Bay-Delta successfully by filling new habitat niches that previously did not exist. Restoration of natural habitats with more natural flow regimes and hydraulic conditions throughout the Bay-Delta will hopefully favor native species. Continued study of the effects of non-native species on the abundance and distribution of native species and on the rest of the Bay-Delta ecosystem will be part of the adaptive management program guiding these restoration efforts.

STRESSOR DESCRIPTION

Invasive aquatic organisms are those non-native fish and invertebrates that have invaded the Bay-Delta at the expense of native species. Non-native aquatic invertebrates of the Bay-Delta include a wide variety of sponges, coelenterates, worms, molluscs, and crustaceans. Most are bottom- dwelling organisms as adults, but some planktonic forms have also become well established, especially in the last few years. Most were introduced accidentally from the hulls of ships passing through or abandoned or sunk in the Bay-Delta, from the release of ship ballast water, and from oysters (which usually contain dozens of nestling, symbiotic and parasitic invertebrates) brought in from Japan and the Atlantic coast for aquacultural purposes.

The first recorded introduced species, the Atlantic barnacle (*Balanus improvisus*) was observed in 1853, the single busiest year of clipper ship landings of the Gold Rush era. Since then, many species of non-native fish and invertebrates have been introduced into the estuary. The success of these introduced species is due in part to the comparatively small number of native species thought to have been present during aboriginal times and in part to

environmental modifications to which non-native species were often preadapted.

The relatively low native-species diversity is thought to be a result of the relatively young age of the Bay-Delta estuary and its isolation from other Pacific Coast estuarine systems (Carlton 1979). Important environmental changes that most likely decreased native species' ability to compete with non-native species include changes in Bay-Delta morphometry, vegetation, hydraulics, and the amount and timing of Delta outflow.

It is not clear to what extent the decline in abundance of some native species is a result of environmental changes or to interactions with non-native species. It is known, however, that non-native species now figure prominently in the diets of fish species, shorebird and invertebrate-eating waterfowl, and other wildlife species. Most non-native fish and invertebrates perform a vital role in the Bay-Delta foodweb. Certain species, however, have become so abundant in some areas or have been shown to exert a negative effect on ecosystem health or economics in other areas that their mere presence in the Bay-Delta is a source of considerable concern.

The Asian clam, *Potamocorbula amurensis*, was first observed in 1986 and has since become extremely abundant in the Bay and western Delta. This species is well adapted to the Bay-Delta saltwater conditions and exerts a heavy grazing loss on phytoplankton and zooplankton in the Bay. Precisely how the Asian clam is affecting other benthic invertebrates, the zooplankton abundance and composition, or the larval and young fish health is still not well understood, but is thought to be generally detrimental. This is especially true for native species. On the positive side, Asian clams may contribute to the foodweb as an important food source for white sturgeon (Peterson 1997).

The zebra mussel, *Dreissena polymorpha*, another clam-like species many believe will soon invade the Bay-Delta, poses a similar ominous threat.

The Asian clams came on the heels of another clam invasion. *Corbicula manillensis* was also introduced from Asia. It was first described in the Delta in 1946. This clam does not tolerate saline waters. It is now very abundant in freshwater portions of the Delta and in the lower mainstem rivers adjacent to the Delta.

Another relatively new arrival to the Bay-Delta is another species from the Orient, the Chinese mitten crab (*Eriocheir sinensis*). This crab spends most of its life in fresh water and migrates downstream to spawn in salt water. Mitten crabs were first captured in south-Bay shrimp trawls in 1993. Their distribution and abundance have increased every year since then (Hieb 1997). Although these crabs may have an adverse effect on the red swamp crayfish (another non-native species), its greatest potential negative impact on the Bay-Delta may be its effect on levees. Mitten crabs dig burrows in clay-rich soils where banks are steep and lined with vegetation. These burrows accelerate bank erosion and slumping and, over time, may pose a serious threat to Delta levee integrity. The crabs also interfere with bay shrimp fishing by fouling nets.

Introduced zooplankton species have become important elements of the Bay-Delta. *Eurytemora affinis* was probably introduced with striped bass around 1880. Until recently, it was a dominant calanoid copepod of the entrapment zone. In the last decade, however, Eurytemora has been replaced by two calanoid copepods introduced from China. This replacement was a result, in part, of Eurytemora's greater vulnerability to Asian Clam grazing.

The native mysid shrimp, *Neomysis mercedis*, began dwindling in abundance in the late 1970s primarily as a result of the declining trophic status of the Bay-Delta. Its population decline was also affected by competition with *Acanthomysis aspera*, an introduced mysid shrimp of somewhat smaller size but similar feeding habits.

Although many non-native fish species have been introduced to the Bay-Delta over the past century, only a few have been considered invasive and requiring control. The most recent example is the northern pike introduced into Davis Lake, a State Water Project reservoir on the Feather River. Two unconfirmed sightings of northern pike occurred in the Delta in early 1997. Northern pike are noted predators and could, if allowed to establish themselves, pose a significant threat to native fishes, such as chinook salmon, steelhead, and delta smelt. White bass were a similar threat in the 1980s; however, a concerted effort ensured they did not move from isolated southern San Joaquin Valley reservoirs into the San Joaquin River.